Proceedings of the National Seminar & Exhibition on Non-Destructive Evaluation
NDE 2011, December 8-10, 2011

ACTIVE INFRARED THERMOGRAPHY FOR NON DESTRUCTIVE EVALUATION OF DEFECTS IN WEAR RESISTANCE AND THERMAL BARRIER COATINGS

M. Mahesh Kumar*, M. Swamy*, M.S. Rawat * K.S Vikrant*, V, John Thomas*and R Markandeya**
* Metallurgy Department,Bharat Heavy Electricals Limited (R & D), Hyderabad, India
** JNTUH College of Engineering,Kukatpally, Hyderabad, India

ABSTRACT

In fossil fuel power generation plants, steam generation tubes and turbine blades are critical for overall performance of plant. The materials are subjected to bear heavy wear and temperature during operation. The manufacturer has an option of using high wear resistant and high temperature materials which are costlier or using cheaper materials with ceramic coatings over it. The coatings exposed to harsh conditions will withstand mechanical and thermal stresses, hence coating needs to be adhered properly on the material. Coatings of 300-500 micron thickness serve the purpose and the techniques available for spray are High Velocity Oxy Fuel (HVOF), Plasma, Twin wire arc, etc. The evaluation of coatings w.r.t quality is required to be done for required life of components.

Comparing to the traditional Non-Destructive Tests such as Acoustic Emission, Ultrasonic, and Eddy Current, Magnetic Particle and Radiography Tests where experimental equipment is non-portable, tedious and time consuming and difficulties during interpretation of results. A new approach Infrared Thermography Testing (IRT) has been introduced for qualitative evaluation of coatings. In this technique, high energy optical source along with Pulse phase thermography system has been used for detection of surface and sub surface coating defects in Wear resistant and thermal barrier coatings. Pulse phase thermography is helpful in finding defects in high reflecting and thermal conductive materials like steel. The IRT methodology and IR results are discussed in this paper.

***Keywords*:** Pulse Phase Thermography, Coatings, Wear Resistant, Thermal Barrier Coatings, Components.

INTRODUCTION

The pulsed phase thermography (PPT) is a well known method in non-destructive testing in assessing engineering material because of its simplicity and fast inspection results. It combines features of pulse thermography (PT) and lock-in thermography (LT) [1]. The experimental set-up and data acquisition are identical for both, PT and PPT, whereas data analysis procedures are different. In PPT, on the contrary to PT, each pixel's time history of a series of consecutive thermograms, which describes the transient cooling down behaviour of the inspected specimen surface after a heating pulse, is analysed by application of discrete Fourier transformation (DFT) [2]. The computed phasegrams are excellent for defect visualization in a wide range of materials [3]. This is partly due to their low sensitivity to uneven heating. However, DFT can be often unavailing within a time domain of thermal data, acquired by relatively low cost infrared scanned detector cameras, first of all because of their slow data acquisition rate and low spatial resolution. This paper presents an efficient approach towards preprocessing of raw, time dependent experimental thermal data sets obtained by this type of infrared imagers, before their 1D DFT treatment, as well as the approach to their post processing after frequency analysis.

EXPERIMENTAL PROCEDURE

The experimental data set of thermal barrier coating on Steel plate made, of thicknesses,185-*450***μ** *for study*. 6 KJ of energy given with flash lamps for 2 ms maintained at distance of 1meter. A CEDIP camera of 5500-M make used to detect the thermal decay curve using a short wave band (*3-5* μ*m*). The experimental setup for performing measurements on plain carbon steels with wear resistant and thermal barrier coating requires- an excitation source, power electronics module, IRX Box and a panel with Halogen Lamps and IR-NDT software. During experimentation a special image sequence file formation is studied & analyzed and the resultant thermal wave signal Fourier Transform algorithm are researched to obtain the Phase angle image of thermal wave on the surface of sample. The experimental results show that the lock-in thermography software helps in distinguishing surface and subsurface defects. Further, the Amplitude and Phase angle images were processed in Image Processing through MATLAB(student version) software.

In the following presented one-dimensional case the solution has the shape of an oscillation with a damping factor and a proportion, which describes the phase shift.

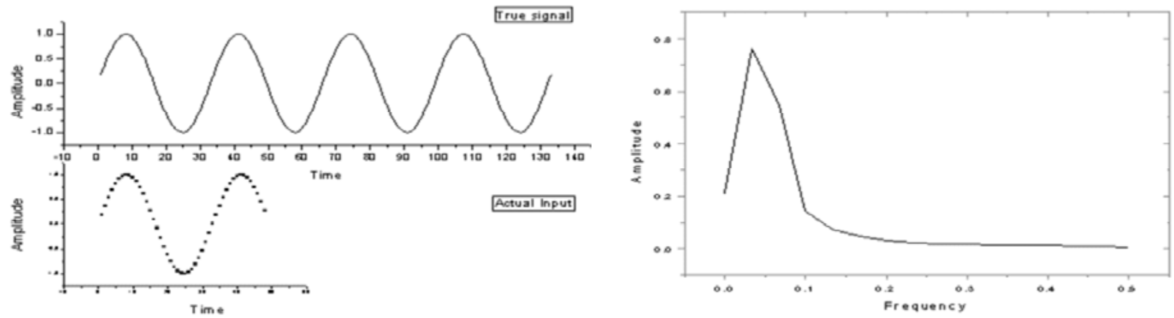

Fig. 1 : The true signal and actual input

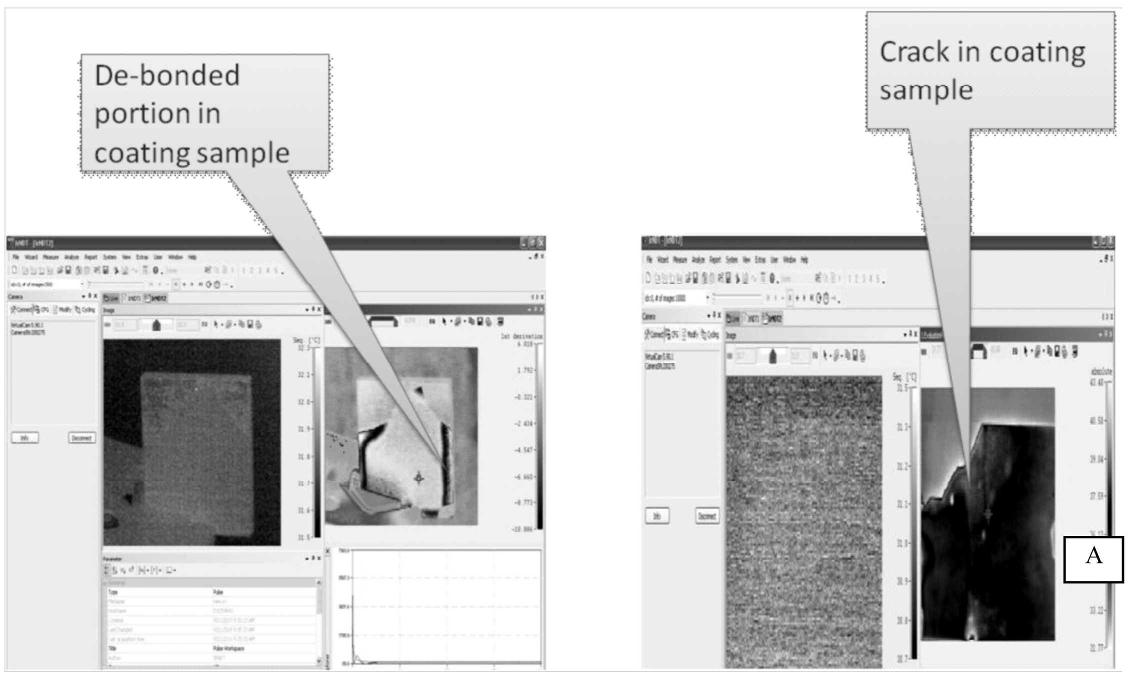

Fig. 2 : Wear resistance coating and debond in gas turbine blades using the above experimental setup

$$T(z,t)=T_0\, e^{-\sqrt{\frac{\omega\rho c}{2\lambda}}z} \cos\left(\omega t+\sqrt{\frac{\omega\rho c}{2\lambda}}\, z\right)$$

λ = Thermal Conductivity
ω = Angular Frequency, 2π*Fe (Excitation Frequency)
ρ = Density
c = Specific Heat Capacity
z = Coordinate

$$\mu=\sqrt{\frac{2\lambda}{\omega\rho c}}=\sqrt{\frac{2a}{\omega}}$$

As one can see, the decrease of the amplitude of the thermal wave with increasing material depth depends and on the thermo physical properties and the stimulation frequency. Within a depth ofThe amplitude drops to 37% (1/e) of the surface value. The characteristic length m is called thermal penetration depth. It is a function of the thermal diffusivity of the examined material and of the excitation frequency.

ANALYSIS OF GIVEN SPECIMEN DATA

Fast Fourier Transform (FFT)

DFTs with a million points are common in many applications. Modern signal and image processing applications would be impossible without an efficient method for computing the DFT.

Direct application of the definition of the DFT to a data vector of length n requires n multiplications and n additions—a total of $2n^2$ floating-point operations. This does not include the generation of the powers of the complex nth root of unity ω. To compute a million-point DFT, a computer capable of doing one multiplication and addition every microsecond requires a million seconds, or about 11.5 days.

(FFT) algorithms have computational complexity $O(n \log n)$ instead of $O(n^2)$. If n is a power of 2, a one-dimensional FFT of length n requires less than $3n \log_2 n$ floating-point operations (times a proportionality constant). For n = 220, that is a factor

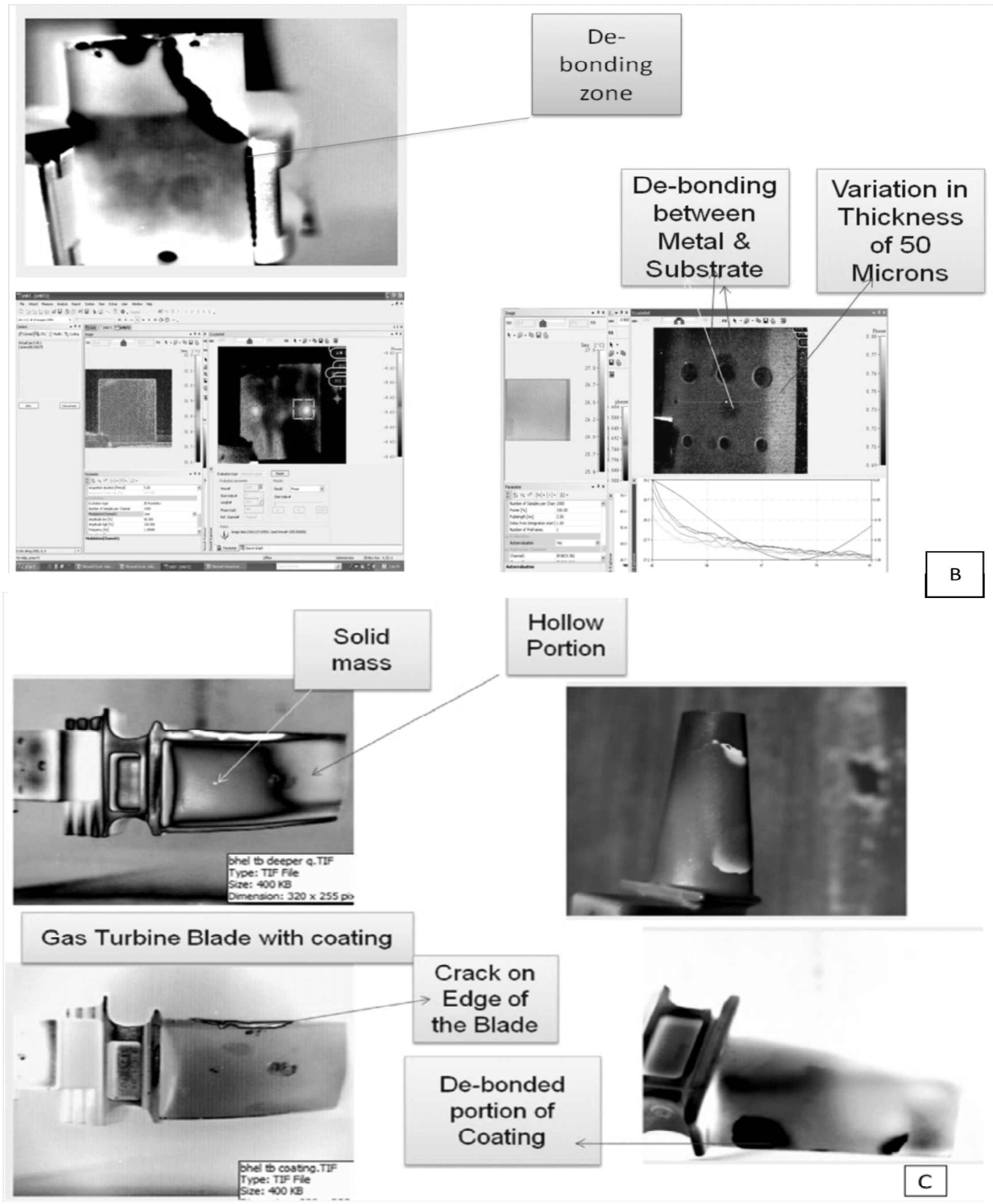

Fig. 3 : Debonding and Crack region of Gas Turbine Blade using flash Thermography

of almost 35,000 faster than $2n^2$. A discrete Fourier transform (DFT) is a process that converts a signal in time domain into its counterpart in frequency domain. Let $\{x_i\}$ be a sequence of length N, then its DFT is the sequence $\{F_n\}$ given by

$$Fn = \sum^{N-1} Xi^* e^\wedge -j2\pi(n/N)\, i$$

The acquired consecutive thermograms were converted into a scaled intensity thermal images series with an arbitrary selected interval of the sampled time history of each discretionary selected rectangular region of pixels of any its thermal image. The full time series of complete converted thermograms was chosen as a region of interest in the described thermographic measurement. Having these samples of the original time dependent thermal signal, the DFT can be applied to estimate the potential capabilities of analysis in the frequency domain.

RESULTS AND DISCUSSION

The results of the described power spectral analysis for frequencies of *0,3, 0,6* and *4,8 mHz* are presented in Fig. 2-3(A-C). Currently these frequencies namely provide a sufficient of energy for a noticeable visualisation of hidden defects of various sizes located in different subsurface depths. The darkest point in Fig. 1arepresents a relatively shallow subsurface flaw or a little inclusion situated fairly deeply because at higher frequencies, with the absence of the external thermal stimulus energy for a deeper penetration into the tested material, it fades from the power spectral pictures. On the other hand, both defects visible in Fig. 1b and Fig. 1c are much larger because of their strong visibility in the wider frequency band. At the same time, these defects of various sizes must be also situated deeply below the surface considering their detectability already at very low frequency. The right one is larger and deeper as it provides a higher contrast on the low frequency picture.

CONCLUSIONS

The described approach of raw data series arrangement, conversion and rearrangement of it into the concentrative thermal image, with the following wavelet-based extension and its resampling as one-dimensional multichannel discrete thermal signal, makes possible the effectual power spectrum analysis in the frequency domain that returns the relatively strong subsurface defects sensitive power spectrum images.The experimental data is relatively simple for finding defects in coatings and techniques can be utilised for fast and accurate measurement.

REFERENCES

1. Brighman E. O. The Fast Fourier Transform, Englewood Cliffs, NJ, Prentice-Hall, Inc., 1974.
2. Favro L. D. and Han X. “Thermal Wave Materials Characterization and Thermal Wave Imaging,” in Birnbaum G., Auld B. A. (eds.): Sensing for Materials Characterization, Processing and Manufacuring, ASNT TONES, vol. 1, p. 399-415, 1998.
3. Ibarra-Castanedo C., González D., Klein M. Pilla M., Vallerand S. and Maldague X. “Infrared Image Processing and Data Analysis,” Journal of Infrared Physics and Technology, in press 2004.
4. Ibarra-Castanedo C. and Maldague X. “Defect Depth Retrieval from Pulsed Phase Thermographic Data on Plexiglas and Aluminum Samples,” Thermosense XXVI, Proc. SPIE, vol. 5405, p. 348-356, Orlando, April 2004a.
5. Clemente Ibara-Castanedo, Marc Genset *et al*. Inspection of aerospace materials by pulse thermography, lock-in thermography and virbothermography: A comparative study. Thermosense XXIX, Proc. of SPIE Vol.6541, 654116-1:9, (2007)
5. KOU Wei, SUN Feng-rui, YANG Li. Thermal responses of defect under sinusoidal heating. Infrared and Laser Engineering, Vol 36, No.4 2007.08, 472:474
6. Pierre BREMOND. Nondestructive testing by heat wave detection. 2002. http://www.Cedip-infrared.com/articles.
7. Datong Wu, Gerd Busse. Lock-in thermography for nondestructive evaluation of materials. Cen. Therm. (1998) F693-703
8. G. Busse, D Wu and W.Karpen. Thermal wave imaging with pahse sensitive modulated thermography. Journal of Applied Physics. 1992.01 F3962-3965.